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PALEOBOTANY OF THE BIOGENIC UNIT OF THE LEFFE FORMATION (EARLY PLEISTOCENE, NORTHERN ITALY): BRIEF REPORT ON THE STATE- OF-THE-ART*

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RIASSUNTO - *Paleobotanica dell'unità biogenica della Formazione di Leffe (Pleistocene inferiore, Italia settentrionale): breve resoconto sullo stato dell'arte* - Il Quaternario *Italian Journal of Quaternary Sciences,* **8**(2), 1995, 435-442 - Questo lavoro è un breve sommario dello stato dell'arte sulle ricerche condotte per lo studio del Bacino di Leffe (Italia settentrionale), dopo la costituzione, a Milano, di un apposito gruppo di lavoro per la revisione della serie di Leffe. E' stato eseguito un nuovo *record* pollinico, integrato con analisi preliminari sui macrofossili, delle ligniti e dei sedimenti lacustri che sono contenuti nella serie mediana di Leffe (la cosiddetta "unità biogenica" del Pleistocene inferiore). Vengono sottolineati i problemi che i dati paleobotoanici pongono e che riguardano il paleoambiente, i tipi di migrazione della vegetazione, il paleoclima e la biostratigrafia degli inizi del Quaternario. Vengono citati i lavori specifici che trattano questi problemi in modo dettagliato. E' da notare come varie piante boschive, che risultano estinte nell'Europa centrale sin dal tardo Pliocene, erano ancora viventi nelle paludi di Leffe nei periodi più caldi degli inizi del Quaternario. La loro presenza risulta discontinua, modulata da cambiamenti climatici ciclici. I tradizionali criteri biostratigrafici, che sono basati sull'ipotesi di una progressiva estinzione delle piante terziarie, sono di difficile applicabilità quando si ha a che vedere con una tale evoluzione rapida e ciclica della vegetazione.

ABSTRACT - *Paleobotany of the biogenic unit of the Leffe Formation (early Pleistocene,* N *Italy): brief report on the state-of-the-art* - Il Quaternario *Italian Journal of Quaternary Sciences,* **8**(2), 1995, 435-442 - This paper briefly summarises the state-of-the-art of the palæobotanical research in the Leffe Basin (N-Italy), after constitution of a working group in Milan for the revision of the Leffe sequence. A new pollen record, integrated by preliminary macrofossil analyses, has been carried out in browncoal and lacustrine sediments in the middle Leffe sequence (the "biogenic unit" dating to the Early Pleistocene). Several problems araising from the palæobotanical data are pointed out concerning the paleoenvironment, migration patterns of vegetation, palæoclimatology and biostratigraphy at the beginning of the Quaternary. Reference is made to specific papers where these problems are examined in more detail. It is noteworthy that several woody plants, extinct in Central Europe since late Pliocene times, were still living in the Leffe mire during the warmest periods at the beginning of the Quaternary. Their record is discontinuous and it is modulated by cyclical climatic changes. Traditional biostratigraphic criteria, mainly based on a supposed progressive extinction of Tertiary plants, meet with substantial difficulties when applied to such rapid and cyclical evolution of vegetation.

Key words: Paleobotany, climatic changes, early Pleistocene, Leffe Formation, N Italy
Parole chiave: Paleobotanica, variazioni climatiche, Pleistocene inferiore, Formazione di Leffe, Italia set0tentrionale

1. INTRODUCTION

This paper summarises the first results of a biostratigraphic re-evaluation of the lacustrine and palustrine succession of the "biogenic unit" in the Leffe Basin sequence (Lombard Pre-Alps, N-Italy), based on new palaeobotanical investigations(1) supported by a new geological survey and geomagnetic studies.

The geological evolution of the area during the Late Tertiary and Quaternary has been discussed in detail by Ravazzi (1993) and Cremaschi & Ravazzi (1995). Only a brief outline is presented here.

The Leffe Basin is located in a small valley, cut through Triassic carbonates and surrounded by 1,000÷1,600 m high mountains, 15 km from the southern margin of the Pre-Alps (see Cremaschi & Ravazzi, 1995, fig. 1). The basin dates to Upper Pliocene times, during which the Po plain area was taken up by the sea, lapping the southern margin of the Lombard Pre-Alps.

The entire Leffe sequence consists of two complex stratigraphic units: the lower one (Leffe Formation) is composed of fan-delta, lacustrine and palustrine deposits, of Pleistocene age. The Leffe Formation is conformably overlaid by the *Gandino* Formation, composed of conglomerates and turbiditic lacustrine deposits dating to the Early Pleistocene.

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Lavoro presentato al Convegno "Il significato del Villafranchiano nella stratigrafia del Plio-Pleistocene", Peveragno-Villafranca d'Asti 24-29 giugno 1994.

(1) The paleobotanical researches constitute part of the research project "The continental succession of the Leffe Basin", among the programs of the *CNR - Centro Geodinamica Alpina e Quaternaria* in Milan. The financial support by the CNR Center, as well as by *Museo Civico di Scienze Naturali di Bergamo,* and by *Comunità Montana Val Seriana,* made it possible.

2. STRATIGRAPHIC POSITION OF THE BIOGENIC UNIT

The middle subunit of the Leffe Formation (biogenic unit) is especially important from a biostratigraphic point of view. It consists of a lacustrine and palustrine, 80 m-thick succession, made up of biogenic carbonate deposits, alternating with three organic layers (browncoal and *gyttja*). The middle one, more than 8 m thick, is called the "Main" browncoal layer.

On the basis of new paleomagnetic investigations (Billard *et al.*, 1983; Ravazzi *et al.*, 1992), the biogenic unit belongs to the Matuyama epoch, starting shortly after the upper reversal of the Olduvai event and ending well before the base of the Jaramillo event.

A rich fauna is included in the browncoal seams of the biogenic unit which has been known since the last century (Sordelli, 1896; Sthelin, 1930). This unit belongs to the Upper Villafranchian Mammal Age (Azzaroli *et al.*, 1986), and most probably to the Tasso or the Farneta Faunal Unit (according to Masini *et al.*, 1994 and Ambrosetti *et al.*, 1995). Another faunal assemblage, which includes *Elephas meridionalis vestinus,* was discovered in the Fifties during clay exploitation in the upper unit of the Leffe Formation which overlies the biogenic unit (Vialli, 1956). The stratigraphic position of this assemblage, previously attributed to the Cromerian (Vialli, 1956; Lona & Follieri, 1957), has been re-assigned to the Upper Villafranchian (Azzaroli *et al.*, 1986).

3. PALEOBOTANICAL INVESTIGATIONS IN THE BIOGENIC UNIT: PROJECT STRUCTURE

The pollen record by Lona (1950) in the biogenic unit outlined several climatic cycles. The new palynostratigraphic investigation has so far addressed the detailed description of a particulary well expressed cycle (Ravazzi & Rossignol Strick, 1995) in the 49÷33 m interval of a new 186 m long core, taken in 1991 (Ravazzi *et al.*, 1992).

Only a few macroremains can be studied from this interval given the small quantity of material available. Consequently, several sections cropping at different stratigraphic positions have been sampled and tentatively correlated with the core. The main sites under study both for macro- and microfossils are:

a) The main browncoal layer (8 m thick) excavated in 1992 at *Villa Giuseppina* site, from where coniferous wood has been studied (Ravazzi & Van der Burgh, 1994).

b) Deposits with coniferous macroremains, dominated by *Tsuga,* buried by a slide along the paleoslope at the border of the Leffe Basin (Ravazzi *et al.*, in prep.).

c) Fluviatile deposits interfingering with the lower unit of the Leffe Formation, where a rich carpoflora has been recovered (Casnigo site: Martinetto & Ravazzi, in preparation).

4. TAPHONOMY

The taphonomical processes involved in pollen dispersal and sedimentation, the catchment area of the Leffe Basin, the topography of the paleolake and diagenetic processes have been discussed by Ravazzi (1993, pp. 193-204). Moreover, a comparison between pollen and macroflora is in progress (Ghiotto *et al.*, in prep.; Pini, in prep.) to provide more insight into the distinction of the local, extralocal and regional components of the flora.

During the accumulation of the biogenic unit, the lake was isolated from the main river (Cremaschi & Ravazzi, 1995). Therefore, the regional component of pollen flora from the lacustrine and palustrine deposits was mostly supplied by a local wind circulation and by local rivers, draining a small, isolated catchment area (39 km^2) surrounding the lake and bounded by high mountains. There is geological evidence that Tertiary deposits were absent in the catchment basin during the accumulation of the biogenic unit. Moreover, no sinsedimentary reworking structures have been observed (Ravazzi, 1993). Accordingly, reworked microfossils have not been recognized in these deposits.

In these taphonomic conditions, a change in pollen assemblages reflects vegetation development in the catchment area. Thanks to the isolated position of the lake, the comparison of a single pollen curve with the general evolution of the dominant vegetation can suggest whether it was autochthonous to the lake surroundings, or at least within the Lombard pre-alpine region (*taxa* such as *Aesculus, Nyssa, Rhododendron ponticum* type).

The macrofossil record helped to confirm that some plants were growing in the local (palustrine), or extralocal (wet plain, bottom valley woodlands) environment (e.g., *Aesculus, Glyptostroboxylon, Chamecyparis, Phellodendron*) (Ravazzi, 1994; Ravazzi & van der Burgh, 1994). However, in several cases, the only evidence available are high pollen concentrations (and estimated pollen influx), or a pollen record with a strictly local character (*i.e.,* hygrophilous plants whose pollen occurs ex-clusively in the browncoal). The case of *Cedrus* is a good example of the first situation; high values of pollen concentration (reaching 13,000 grains/g and an estimated pollen influx of 260 grains/cm^2yr in marls of the biogenic unit) indicate that an extensive forest populated the mountains of the catchment area during sedimentation. However, macroremains have never been found in Leffe and only once in Italian Pleistocene deposits (Mastrorilli, 1965). *Cedrus* cone scales break away from the rachis near maturity; a single scales is very rarely transported from the dry habitat of this tree to a sedimentary basin (Spicer & Wolfe, 1987).

Evaluation of taphonomical processes as outlined above allowed the reconstruction of the local and regional vegetation (sections 5 and 6), and to understand the stratigraphic record of "Tertiary plants" section 7).

5. THE LOCAL VEGETATION

The pollen record of the biogenic unit is dominated throughout by arboreal *taxa* as well as local herbs and ferns growing *in situ* . The pollen diagrams are discussed in Ravazzi (1993) and Ravazzi & Rossignol Strick (1995) and only the vegetation reconstruction is presented here.

The local vegetation is especially important in the browncoal seams, which accumulated during phases of fen (herbaceous) and swamp (with tree layer) vegetation. Different types of communities growing in the mire have been documented on the basis of pollen, wood and browncoal composition.

Herbaceous communities

– Terrestrial or telmatic hygrophilous communities accumulating peat, dominated by *Phragmites,* or Cyjperaceae (dominant *taxa: Carex sect. Acutae, Carex sect. Rostratae, Scirpus, Hypericum*). In some browncoal levels, mosses or ferns are dominant both in the palynoflora and in macroremains (*Thelypteris, Osmunda regalis*-type).

– Aquatic hydrophilous communities (*Potamogeton, Nymphaea, Nuphar, Sparganium minimum*). Pollen, seeds and trichosclereids of Nymphaeaceae (Pals *et al.*, 1980) are relatively abundant in peat and in *gyttja* deposits as well.

Swamps

– An eutrophic type with *Glyptostroboxylon tenerum* (Kraus) Conwentz, *Chamaecyparis, Nyssa, Pterocarya, Alnus* has been identified. This vegetation has been described from several Neogene browncoal sites in Central Europe [the Rhenish Basin (Teichmüller, 1958; Van der Burgh, 1987; Huhn *et al.*, 1994), the German-Polish depression (Schneider, 1990), the Cheb Basin in the Czech Republic (Buzek *et al.*, 1985)] and western North Italy (Martinetto, 1995). No Quaternary record in Europe has to date been identified.

– A vegetation type dominated by different species of *Picea. Picea* needles, together with Coniferous periderms and wood, has been found in distinct browncoal levels, and coincides with peaks of *Picea* pollen. From the pollen record, it appears that at least one species belonging to *P. excelsa*-type and another to the *P. omorika*-type appear to have been present in the local swamp vegetation. Macrofossils recovered in browncoal have been identified as *P. seriana* Sordelli (= *P. omorikoides* Weber ?), *P. balsami* Sordelli, *Picea* cf. *excelsa* foss. (Sordelli, 1896). A Late Pliocene swamp vegetation with *P. omorikoides* Weber has been described in Buzek *et al.* (1985) in the Czech Republic.

– An oligotrophic type vegetation, with *Sphagnum* spores and pollen peaks of *Pinus sylvestris*-type. Wood identified as *Pinus* cf. *tabulaeformis* Carrière has been found in the same levels (Ravazzi & Van der Burgh, 1994).

The stratigraphic occurrence of these communities shows clear relationships with the development of the local vegetation, the regional vegetation, and climate (Ravazzi, 1993). For instance, mosses and ferns are never associated in the same stratigraphic interval, as are the first two types of swamp vegetation. Therefore, a floral list not-stratigraphycally controlled from the Leffe browncoal (like that by Gregor, 1990) does not allow any deductions on the ecology of vegetation and paleoclimate to be made.

6. THE EVOLUTION OF THE REGIONAL VEGETATION AND CLIMATE CHANGE

The pollen record of extralocal and regional vegetation and the climate evolution is described in Ravazzi & Rossignol Strick (1995). It shows a repetitive forest succession of a mixed oak forest in a dry-temperate climate, followed by a Juglandaceae assemblage rich in Arcto-Tertiary elements, some of them indicating a wet climate (*Carya sp. pl., Pterocarya, Fagus, Aesculus* aff. *hippostanum*), and a long phase of coniferous forests of cooler climate (*Picea, Tsuga, Cedrus, Abies*). A short phase of open vegetation (*Artemisia-Betula-Larix* pollen zones) interrupts this forest succession. It indicates a short event of drier and colder, continental climate.

By correlating the new pollen record with the data by Lona (1950), the complete vegetation dynamics seems to have been repeated at least seven times in the entire time interval represented by the biogenic unit.

Contrary to what outlined by Venzo (1950) and Lona (1950), thh new pollen record and stratigraphic data show that these vegetation cycles cannot be related to the main glacial periods in the Alps described by Penck & Brückner (1909), but rather to high-frequency climatic cycles of moderate amplitude (Cremaschi & Ravazzi, 1995; Ravazzi & Rossignol Strick, 1995). A similar cyclicity has been observed in deep-sea cores of Early Pleistocene age (Ruddiman *et al.*, 1986; 1988; 1989) and in Mediterranean sapropel stratigraphy (Hilgen, 1987, 1991; Combourieu-Nebout, 1993; Lourens *et al.*, in press). Although the duration of the observed cyclicity in Leffe is still under study (Ravazzi & Moscariello, submitted), a period of about 30 ka years can be estimated from counting laminated couplets in marls and from a calculation of sedimentation rate in peat after compression. This value is comparable to the period of the obliquity-driven cycles of 40 Ka.

7. THE CYCLIC RECORD OF RELICT PLANTS FROM TERTIARY

The new floral record from the biogenic unit points to the Quaternary persistence in the Southern Pre-Alps of several plants traditionally regarded as extinct in Eu-

rope at the end of the Tertiary, or surviving as relicts during the Early Pleistocene (Van der Hammen *et al.*, 1971). Most of these plants are occurring only during the warm-temperate and wet intervals of the Leffe record.

The following list includes exotic and other *taxa* of special interest for biostratigraphy, found in the biogenic unit and clearly autochthonous to the catchment area of the Leffe Basin. The criteria used to define autochthony have been briefly discussed in section 4 and are in agreement with criteria defined by the AIQUA Working Group on Quaternary Stratigraphy (AIQUA, 1995). Part of paleobotanical material is described in Ravazzi (1993; 1994) and in Ravazzi & Van der Burgh (1994). However, carpofloral identifications are still unpublished (Ghiotto *et al.*, in prep.).

The nomenclature follows Beug (1961), Moore *et al.* (1991); further taxonomical references are reported in the list.

Conifers

Cedrus aff. *atlantica* (pollen) (Montagnana, 1991; Ravazzi, 1993)
Chamaecyparis / Thuja-type (pollen)
Chamaecyparis (wood)
Glyptostroboxylon tenerum (Kraus) Conwentz (wood)
Taxodium type (pollen)
Tsuga diversifolia type (pollen)
Tsuga (cones and needles)

Angiosperms

Acer palmatum type (pollen) (Skawinska, 1985)
Acer Sect. Saccharina Pax (pollen) (Biesboer, 1975)
Aesculus aff. *hippocastanum* L. (pollen) (Ravazzi, 1994)
Aesculus hippocastanum (seeds) (Sordelli, 1896)
Carya sspp. (pollen, fruits and wood)
Celastraceae
Eucommia (pollen)
Jasminum (pollen)
Juglans bergomensis Massal. (fruits) [(Balsamo Crivelli) Massalongo, 1852]
Juglans Sect. Trachycaryon (pollen) (Stone & Broome, 1975) (= *J. cinerea*-type)
Liquidambar cf. *orientalis* Mill. (pollen)
Magnolia cor Ludwig (seeds)
Nyssa aff. *sylvatica* L. (pollen) (Lieux, 1983)
Parthenocissus (pollen)
Phellodendron (seeds)
Pterocarya (pollen, wood)
Rhamnus aff. *alaternus* L. (pollen)
Rhododendron ponticum-type (pollen)
Staphylea (pollen)

Taxa to be excluded

Cathaya bergeri (Kirchheimer) Schneider. The finds reported by Gregor (1990) are erroneous, because these cones, which originate from the collections of the *Museo Civico di Scienze Naturali di Bergamo,* belong to *Pinus peuce* and are registered as coming from the Pianico Basin (Middle-Late Pleistocene), and not from Leffe.

Keteleeria (Lona & Bertoldi, 1973, table 1, fig. 1). The distinction between *Keteleeria* and *Abies* pollen is not documented by diagnostic characters.

The pollen record of most of the above listed *taxa* is discontinuous and modulated by climatic change. A cyclic, repetitive appearance-disappearance of a number of thermophilous woody plants, some of them characteristic for the mixed mesophytic forest (Braun, 1950; Wolfe, 1971) including several relict plants from the Tertiary, has been observed in the new pollen record (Ravazzi & Rossignol Strick, 1995), i.e., *Aesculus* aff. *hippocastanum, Carya, Celtis, Eucommia, Juglans Sect. Trachycaryon, Parthenocissus, Pterocarya,* and *Vitis.* Among "Tertiary plants", a group including Taxodiaceae e.g. *Glyptostrobus, Nyssa, Magnolia,* Cupressaceae e.g., *Chamaecyparis,* shows a more time-restricted occurrence, decreasing towards the top of the biogenic unit of the Leffe Formation.

Although these plants show a time-restricted record and low quantitative values, their repetitive appearance and disappearance suggests a migration regime from short-distance refugia to the Pre-Alps during periods of favourable climate. A discussion of the relationships between migration induced by climate changes, paleogeography and geological evolution of the southern alpine fringe at the beginning of the Quaternary requires an overview which cannot be provided. So far the marine/continental transition and the oldest fluviatile deposits in the Lombard plain have not been dated, so that any attempt to correlate between the deposits in the valley floor of the Lombard Pre-Alps and in the plain is still unambiguous.

On the other hand, evidence for migration processes make it hard to develop stratigraphic inferences simply from the floral composition of a deposit. A temporary disappearance, produced by vegetation dynamics, can easily be misidentified as a stratigraphic extinction. Traditional biostratigraphic criteria, mainly based on the progressive extinction of "Tertiary relicts" (Van der Hammen *et al.*, 1971), meet with substantial difficulties when applied to such a cyclical and rapid floral evolution.

The biostratigraphic signal provided by the extinction of exotic plants may be used only in the context of large-scale biostratigraphy. For this purpose, a careful selection of irreversible events in a definite region has to be operated. The absence of *taxa* in the Leffe sediments whose regional extinction has been related by Martinetto (1995) with the cold phase at about 2.6 Ma, could also be relevant. None of those *taxa* with subtropical affinities, reported by Bertoldi *et al.* (1994) and Martinetto (1995) in Early and Middle Pliocene of N Italy, has been recognized in the Leffe floral record.

8. PLIO-PLEISTOCENE STRATIGRAPHY BASED ON FOSSIL PLANTS: A PROBLEMATIC TASK

The classic paleobotanical subdivision of the Pliocene and the Early Quaternary in Central Europe (Mai & Walther, 1988; Gibbard *et al.*, 1991; Zagwijn, 1992) and in the Mediterranean (Suc & Zagwijn, 1983; Suc, 1984; Bertoldi *et al.*, 1994) is based on a large scale time-constraint evolution of the flora and/or vegetation.

It is now clear that, with the high frequency glacial-interglacial couplets at about 3-2.5 Ma (Shakleton, 1995), these large-scale floral assemblages or/and "floral complexes" *(Florenkomplex),* defined by Mai & Walther (1988) as "a group of local fossil floras reflecting a chronologically delimited and distinguishable stage of vegetation", cannot describe biozones, but only a group of isolated points (the local fossil floras) in the stratigraphic record. Migration processes allow the same plants and vegetations to be in the same place before and after a "glacial" event, so that these points cannot be put in an unambiguous time sequence. Therefore, only few large-scale, yet irreversible events allow the establishment of biostratigraphic units as defined for local mammal faunas (De Giuli *et al.*, 1983), i.e. a group of local floras ranging after an irreversible event and before another. The record of local floras is discontinuous and its correlation potential is strongly limited in space. A synthesis of floral complexes, large-scale "climate-themes" (Zubakov & Borzenkova, 1990) and "vegetational provinces" has been attempted recently by Martinetto (1995) and Suc *et al.* (1995). The existence of "supercycles" during the whole Quaternary and even between 2.6 and 1 Ma has been recently asserted by Kukla (1995), based on loess sequences in China. However, this hypothesis has not yet been confirmed in deep sea records. Especially at the base of Early Pleistocene, there is no clear evidence of such large scale, irreversible events enabling to subdivide this time interval in a few stages. The climatic curve for the Pleistocene in The Netherlands (Zagwijn, 1992) shows that climatic oscillations, occurring at the boundaries separating stages (Tiglian, Eburonian, Waalian, Menapian, Bavelian, Cromerian) and during these stages, are of the same amplitude. Therefore, they have scarce potential of large scale correlation. Furthermore, the Leffe record suggests that a regime of high frequency (20÷40 ka) climatic cycles explain the floral evolution during the Early Pleistocene in Northern Italy. Stages longer than a cycle are not visible in the Leffe record so far investigated.

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REFERENCES

AIQUA, W.G. on Continental Quaternary Stratigraphy, 1995 - *The continental Pliocene and Pleistocene of Italy. The state of the art.* XIV INQUA Congress, 1995, Table presented at Symposium 24, Berlin. Terra Nostra, **2**, 1995, 10.

Ambrosetti P., Azzaroli A., Bertini A., Bertoldi R., Carraro F., Esu D., Fusco F., Ghiotto P., Girotti O., Gliozzi E., Kotsakis T., Martinetto E., Pontini R., Ravazzi C., Rook L., Russo Ermolli E., Sala B. & Torre D. 1995 - *The continental Pliocene and Pleistocene of Italy. The state of the art.* Terra Nostra, **2**, 10 (abstract of a poster).

Azzaroli A., De Giuli C., Ficcarelli G. & Torre D., 1986 - *Mammal succession of the Plio-Pleistocene of Italy.* Mem. Soc. Geol. It., **31**, 213-218.

Bertoldi R., Binotti A. & Castello M.F., 1994 - Reevesia *and* Itea *in the pollen flora of the upper Neogene continental deposit at Sarzana (lower Magra Valley, northern Italy).* Rev. Paleobot. Palynol., **80**, 159-172.

Beug, H.J., 1961 - *Leitfaden der Pollenbestimmung.* Lieferung 1, Fischer, Stuttgart, 63 pp.

Biesboer D.D., 1975 - *Pollen morphology of the Aceraceae.* Grana, **15**, 19-27.

Braun E.L., 1950 - *Deciduous forests of Eastern North America.* Free Press, New York, 596 pp.

Buzek C., Kvacek Z. & Holy F., 1985 - *Late Pliocene palaeoenvironment and correlation of the Vildstejn floristic complex within Central Europe.* Academia Nakladatelstvi Ceskoslovenske Akademie ved, Praha, **95**(7), 1-72.

Combourieu-Nebout N., 1993 - *Vegetation response to Upper Pliocene glacial/interglacial cyclicity in the central Mediterranean.* Quat. Res., **40**, 228-236.

Cremaschi M. & Ravazzi C., 1995 - *Nuovi dati stratigrafici e geocronologici sul Bacino di Leffe (Prealpi Lombarde - Bergamo).* Il Quaternario, **8**(1), 167-182.

Ghiotto P., Martinetto E., Pini R. & Ravazzi C., in prep. - Tsuga *communities on a paleoslope at the border of the Leffe Basin: paleobotany and palæoecology.*

Gibbard P.L., West R.G., Zagwijn W.H., Balson P.S., Burger A.W., Funnell B.M., Jeffery D.H., De Jong J., Van Kolfschoten T., Lister A.M., Meijer T., Norton P.E.P., Preece R.C., Rose J., Stuart A.J., Whiteman C.A. & Zalasiewicz J.A., 1991 - *Early and early Middle Pleistocene correlations in the southern North sea Basin.* Quat. Sci. Rev., **10**, 23-52.

Gregor H.J., 1990 - *Contributions to the Late Neogene and early Quaternary floral history of the Mediterranean.* Rev. Palaeobot. Palynol., **62**(3/4), 309-338.

Hilgen F.J., 1987 - *Sedimentary rhytms and high-resolu-*

tion chronostratigraphic correlations in the Mediterranean Pliocene. Newsletters on Stratigraphy, **17**, 109-127.

Hilgen F.J., 1991 - *Astronomical calibration of Gauss to Matuyama sapropels in the Mediterranean and implication for the Geomagnetic Polarity Time Scale.* Earth Planet. Sci. Lett., **104**, 229-244.

Huhn B., Utescher T., Ashraf A.R. & Mosbrugger V., 1994 - *The peat-forming vegetation in the Middle Miocene lower Rhine embayment.* 4th European Palaeobot. and Palynol. Conf., Heerlen, 19 to 23-09-1994, Abstracts.

Kukla G., 1995 - *Supercycles, superterminations and the classical Pleistocene subdivisions.* Terra Nostra, **2**,1995, 149 (Abstract, INQUA Congress, Berlin, August 1995).

Lieux M.H., 1983 - *An atlas of pollen of trees, shrubs, and woody vines of Lousiana and other southeastern States. Part V. Lythraceae to Euphorbiaceae.* Pollen et Spores, **XXV**(3-4), 321-350.

Lona F., 1950 - *Contributi alla storia della vegetazione e del clima nella Val Padana. Analisi pollinica del giacimento villafranchiano di Leffe (Bergamo).* Atti Società Italiana Scienze Naturali, **89**, 123-178.

Lona F. & Follieri M., 1957 - *Successione pollinica della serie superiore (Günz-Mindel) di Leffe (Bergamo).* Veröff. Geobot. Inst. Rübel Zürich, **34**, 86-98.

Lona F. & Bertoldi R., 1973 - *La storia del Plio-Pleistocene italiano in alcune sequenze vegetazionali lacustri e marine.* Mem. Acc. Naz. Lincei, **XI**(III), 1-35.

Lourens L.J., Hilgen F.J., Raffi I. & Vergnaud-Grazzini C., in press - *Early Pleistocene Chronology of the vrica Section (Calabria, Italy).* Palæoceanography.

Mai D.H. & Walther H., 1978 - *Die Floren der Haselbacher Serie im Weisselster-Becken (Bezirk Leipzig, DDR).* Abh. Staatl. Mus. Min. Geol. Dresden, **28**, 1-200.

Mai D.H. & Walther H., 1988 - Die pliozänen Floren von Thüringen, Deutsche Demokratische Republik. Quartäpaläontologie, **7**, 55-297.

Martinetto E., 1995 - *Significato cronologico e paleoambientale dei macrofossili vegetali nell'inquadramento stratigrafico del "Villafranchiano" di alcuni settori del Piemonte (Italia NW).* Tesi di Dottorato in Scienze della Terra, Università di Torino, 149 pp.

Masini F., Rook L., Abbazzi L., Ambrosetti P.L., Azzaroli A., Ficcarelli G., Gentili S., Kotsakis T., Sala B. and Torre D., 1994 - *Mammalian faunas of selected Villafranchian localities of Italy.* In: AIQUA-CNR (ed.) *"Il significato del Villafranchiano nelle successioni Plio-Pleistoceniche"*, Pre-print of the Congress held in Peveragno-Villafranca, 20-24 june 1994.

Mastrorilli V.I., 1965 - *I fossili quaternari del bacino diatomitico di Riano (Roma) nella collezione del Museo civico di Sceinze Naturali "G. Doria" in Genova.* Atti Ist. Geol. Univ. Genova, **III**, 1-245, 36 tavv.

Montagnana S., 1991 - *Contributo alla caratterizzazione tassonomica del polline del gen.* Cedrus. *Confronto con il polline fossile di Leffe.* Sottotesi di Laurea. Univ. of Milano, 59 pp., unpublished.

Moore, P.D., Webb, J.A. and Collison, M.E., 1991 - *Pollen Analysis.* Blackwell, London, 216 pp.

Pals J.P., Van Geel B. & Delfos A., 1980 - *Paleoecological studies in the Klokkeweel bog near Hoogkarspel (Noord-Holland).* Rev. Paleobot. Palynol., **30**, 371-418.

Penck A. & Brückner E., 1909 - *Die Alpen im Eiszeitalter.* Dritter Band. *Die Eiszeiten in den Sudalpen und im Bereich der Ostabdachung der Alpen.* Leipzig, p. 839-842.

Pini R., in prep. - *Evoluzione paleoambientale del Bacino di Leffe (Pleistocene inferiore, Prealpi Lombarde). Studio pollinico e sui macroresti delle torbe del Primo Banco.* Tesi di Laurea, Università di Milano.

Ravazzi C., 1993 - *Variazioni ambientali e climatiche al margine meridionale delle Alpi nel Pleistocene inferiore: stratigrafia ed analisi pollinica della serie di Leffe.* Tesi di Dottorato di Ricerca, Università di Milano, 269 pp.

Ravazzi C., 1994 - *Polline di* Aesculus aff. hippocastanum *nel Bacino di Leffe (Pleistocene inferiore). Posizione sistematica ed inquadramento ecologico.* Giornale Botanico Italiano, **128**(3/4), 751-770.

Ravazzi C., Chiesa S., Cremaschi M., Kissel C., Laj C., Locatelli C., Orombelli G., Paganoni A., Rossi P.M. & Thomas T., 1992 - *A new Plio-Pleistocene continental section in Leffe Basin (Northern Italy).* Actes III Congreso Geologico España - VIII Congreso Latinoamericano Geologia, **2**, 87-90.

Ravazzi C., Ghiotto P., Martinetto E. & Pini R., in prep. - Tsuga *communities on a paleoslope at the border of the Leffe Basin: paleobotany and palaeoecology.*

Ravazzi C. & Moscariello A. (submitted) - *Vegetation succession through multiple climatic cycles at the beginning of Quaternary from the LeffeBasin (N-Italy). Time duration and biostratigraphy.* INQUA-SQS, 16-21 June, 1996.

Ravazzi C. & Rossignol Strick M., 1995 - *Rapid vegetational change in a climatic cycles in the Early Pleistocene of the Leffe Basin (Northern Italy).* Palæogeogr. Palæoclimatol. Palæoecol., **117**, 105-122.

Ravazzi C. & Van der Burgh J., 1994 - *Coniferous woods in the Early Pleistocene browncoals of the Leffe Basin (Lombardy, Italy).* Rivista Italiana di Paleontologia e Stratigrafia, **100**(4), 597-620.

Ruddiman W.F. & Raymo M.E., 1988 - *Northern hemisphere climate regimes during the past 3 Ma: possible tectonic connections.* Phil. Trans. Royal Soc. London, **B318**, 411-430.

Ruddiman W.F., Raymo M.E., Martinson D.G., Clement B.M. & Backman J., 1989 - *Pleistocene evolution: northern hemisphere ice sheets and north Atlantic Ocean.* Paleoceanography, **4**(4), 353-412.

Ruddiman W.F., Raymo M. & McIntyre A., 1986 - *Matuyama 41,000-year cycles: North Atlantic Ocean and northern hemisphere ice sheets.* Earth Planet. Sci. Letters,

80, 117-129.

Schneider W., 1990 - *Floral successions in Miocene bogs of Central Europe.* Proc. Symp. "Palaeofloristic and Palaeoclimatic changes in the Cretaceous and Tertiary", Geological Survey, Prague, 205-212.

Shackleton N.J., 1995 - *The Plio-Pleistocene marine oxygen isotope record.* Terra Nostra, **2**/95, 250 (Abstract, INQUA Congress in Berlin, Aug. 1995).

Skawinska K., 1985 - *Some new and rare pollen grains from Neogene deposits at Ostrzeszow (South-West Poland).* Acta paleobotanica, **25**(1/2), 107-118.

Sordelli F., 1896 - *Studi sulla vegetazione di Lombardia durante i tempi geologici.* Cogliati, Milano. 299 pp & 44 tavv.

Spicer R.A. & Wolfe J.A., 1987 - *Plant taphonomy of Late Holocene deposits in Trinity (Clair Engle) Lake northern California.* Paleobiol., **13**(2), 227-245.

Stehlin H., 1930 - *Die Sugetierfauna von Leffe (Prov. Bergamo).* Ecl. Geol. Helv., **23**(2).

Stone D.E. & Broome C.R., 1975 - *Juglandaceae.* World Pollen and Spore Flora, **4**, 1-35.

Suc J.P., 1984 - *Origin and evolution of the mediterranean vegetation and climate in Europe.* Nature, **307**, 429-432.

Suc J.P., Bertini A., Combourieu Nebout N., Diniz F., Leroy S., Russo-Ermolli E., Zeng Z., Bassais E. & Ferrier J., 1995 - *Structure of West Mediterranean vegetation and climate since 5.3 ma.* Acta zool. cracov., **38**(1), 3-16.

Suc J.P. & Zagwijn W.H., 1983 - *Plio-Pleistocene correlations between the northwestern Mediterranean region and northwestern Europe according to recent biostratigraphic and paleoclimatic data.* Boreas, **12**, 153-166.

Teichmüller M., 1958 - *Rekonstruktionen verschiedener Moortypen des Hauptflözes der niederrheinischen Braunkole.* Fortschr. Geol. Rheinland Westfalen, **2**, 599-612.

Van der Burgh J., 1987 - *Miocene floras in lower Rhenish Basin and their ecological interpretation.* Rev. Palaeobot. Palynol., **52**, 299-366.

Van der Hammen T., Wijmstra T.A. & Zagwijn W.H., 1971 - *The Floral Record of the Late Cenozoic of Europe.* In: Tukerian K.K. (ed.), *Late Cenozoic Glacial Ages.* Yale University Press, New Haven, London, p. 391-424.

Venzo S., 1950 - *Rinvenimento di* Anancus arvernensis *nel Villafranchiano dell'Adda di Paderno, di* Archidiskodon meridionalis *e* Cervus *a Leffe.* Atti Società Italiana Scienze Nat., **89**, 32-122.

Vialli V., 1956 - *Sul rinoceronte e l'elefante dei livelli superiori della serie lacustre di Leffe (Bergamo).* Mem. Soc. It. Sc. Nat., **12**(1), 1-67.

Wolfe J.A., 1971 - *Tertiary climatic fluctuations and meth-ods of analyisis of Tertiary floras.* Palæogeogr. Palæoclimatol. Palæoecol., **9**, 27-57.

Zagwijn W.H., 1992 - *The beginning of ice age in Europe and its major subdivision.* Quat. Sci. Rev., **11**, 583-591.

Zubakov V.A. & Borzenkova I.I., 1990 - *Global paleoclimate of the Late Cenozoic.* Elsevier, Amsterdam. 453 pp.

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